

# A Polarimetric Study of the B[e] star HD 45677

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## ABSTRACT

We present new medium-resolution spectropolarimetric observations of HD 45677 in the *B* and *R*-bands. A change in polarisation is detected across  $H\alpha$ ,  $H\beta$  and  $H\gamma$  confirming that the ionised region around the star is aspherical. (Q,U) points associated with these emission lines occur away from the continuum, defining a polarisation vector which points in the same direction for each of the lines at an average intrinsic polarisation angle of  $164^\circ \pm 3^\circ$ .

These data were combined with past photometric and polarimetric data from the literature to investigate any variability. We find that HD 45677 is both photometrically and polarimetrically variable and that these changes are linked. We suggest that these variations may be caused by an aspherical blowout and by deriving a least-squares fit to the *B*-band polarimetric data in Q-U space, we show that the blowout occurs at an intrinsic polarisation angle of  $175^\circ \pm 1^\circ$ , along the same angle as the proposed geometry of the ionised region.

**Key words:** Techniques: polarimetric - Stars: evolution - Stars: circumstellar environment

## 1 INTRODUCTION

HD 45677 is a B2 V star (Israelian et al. 1996) which was first observed in the late 19th century. Spectroscopic observations revealed forbidden emission lines leading to the star being used as a prototype for the B[e] classification although, ironically, its nature is still unclear (Lamers et al. 1998 and below). These lines suggested the presence of circumstellar gas which implied that the star was evolved as it was not near any star-forming regions. More recent evidence however, such as the absence of CO (1-0), SiO and OH maser emission and the presence of infall features, suggests that the object is not a post-AGB star and may be young (de Winter & van den Ancker 1997; Grady et al. 1993; Muratorio et al. 2006).

The geometry of the circumstellar material was proposed to be disk-like by Swings (1973) from spectroscopic observations. Polarimetric studies by Coyne & Vrba (1976) also suggested that the observed polarisations were most likely due to grains in a flattened disk. Sorrell (1989) modelled the circumstellar environment using a spherical distribution of dust grains and found that the data matched the model quite well. He suggested that any discrepancies may be explained by an aspherical shell. Schulte-Ladbeck et al. (1992) conducted a spectropolarimetric survey of HD 45677. They found that the polarisation spectra in the red and the *UV* significantly differed from one another. Furthermore, after correcting for interstellar polarisation, they observed

a  $90^\circ$  rotation in position angle from the *B*-band to the *UV*. They explained these variations and the angle flip by proposing two sources of polarisation - one that dominates in the red and one in the *UV*. Furthermore, they suggest that the polarisation spectrum is characteristic of a bipolar nebula. Oudmaijer & Drew (1999) conducted medium-resolution spectropolarimetric observations of the object in the optical and concluded that the geometry of the ionised region is either disk-like or bipolar based on changes in polarisation across  $H\alpha$ .

Spectropolarimetry is a powerful tool in probing the inner regions around a star. In particular, the presence of line-effects in a polarisation spectrum can indicate whether there is a non-spherical, ionised region. Line-effects are changes in polarisation over spectral features associated with emission. They occur as a result of the emission line being formed in a volume far larger than the region where electron-scattering is dominant. Subsequently, these emission line photons interact with fewer electrons compared to the continuum light and so experience fewer scatterings, resulting in a lower polarisation at the line-centre.

The aim of this paper is to investigate the geometry of the circumstellar material around HD 45677 by using various polarimetric techniques. To this end, we obtain new spectropolarimetric data and collect past polarimetric and photometric data from the literature.

The paper is organised as follows, in Section 2 we discuss the observational data on HD 45677. We explain the

instrumental setup used in the spectropolarimetric observations and give a brief summary of the past polarimetric and photometric data. In Section 3, we review the photometric results found by authors in the literature and we present new spectropolarimetric data together with past polarimetric data. In Section 4, we investigate the presence of line-effects in the spectropolarimetric data and discuss the links between changes in the photometric and polarimetric data. Finally, conclusions drawn from the study are presented in Section 5.

## 2 OBSERVATIONS

### 2.1 Literature Data

The photometry of HD 45677 was comprehensively reviewed by de Winter & van den Ancker (1997). Therefore, we have used their data and sources within their paper together with more recent data from the AAVSO database (Henden 2006) to build a history of the *V*-band photometry of the star. Table 1 gives a summary of the photometric data collected on HD 45677.

In addition, we have collected *B* and *R*-band polarimetric measurements of HD 45677 from the literature. A list of these observations together with their results can be found in Table 2. Errors were taken directly from the literature. When errors in position angle were not available, they were calculated using

$$\delta\theta = 28^\circ \times \left(\frac{\delta P}{P}\right) \quad (1)$$

### 2.2 Spectropolarimetric Observations

The linear spectropolarimetric data were taken on the 28th and 29th September 2004 using the ISIS spectrograph mounted on the 4.2m William Herschel Telescope (WHT), La Palma. The seeing on both nights was  $< 1.7''$ . The star was observed twice in the *B*-band using a 4096x2048 pixel EEV12 CCD detector with a R1200B grating, which yielded a spectral coverage of 4295-4955Å and a spectral resolution of 51 km/s around H $\beta$ . For the *R*-band observation, we used a MARCONI2 CCD detector with the R1200R grating giving a spectral range of 6150-6815Å and a spectral resolution of 34 km/s around H $\alpha$ . For all of the images a slit width of 1 arcsec was used.

The instrumental setup consisted of a calcite block which splits the light into two perpendicularly polarized beams (the *o* and *e* rays) and a half-wave plate used to rotate the polarisation of the incoming light. There were two extra holes in the dekker mask through which the sky was simultaneously observed, so for each image a total of six spectra were obtained. One complete polarisation set consisted of four (two for the sky and two for the object) measurements taken at 0° and 45° (to measure Stokes *Q*) and 22.5° and 67.5° (to measure Stokes *U*).

Data reduction was carried out using the Figaro software maintained by Starlink, and consisted of bias subtraction, cosmic ray removal, bad pixel correction, spectrum straightening and flat fielding. Wavelength calibration used several spectra (obtained by observing a Copper-Argon lamp) taken throughout the observing run. To obtain the

Stokes parameters, each polarisation set was fed into the Time-Series Polarimetry (TSP) package, also maintained by Starlink. The data was position angle-calibrated using a set of polarisation standard stars observed during the run. Data analysis was carried out using the Starlink package POLMAP.

In principle, polarisation data is only limited by photon statistics. In practice, however, systematic errors such as the effects of scattered light and instrumental polarisation become dominant. The observations of two zero-polarisation objects show that the instrumental polarisation is around 0.10-0.15%.

During our reduction we found large changes in polarisation across the centre of the Balmer lines, whose features were narrower than the spectral resolution. These are most likely related to a slightly different focus in the *o* and *e* rays - we measured a resolution difference of 0.1 pixels between these rays. This difference affects the data considerably where barely-resolved spectral features are present, producing narrow line-effects over the central absorption components of H $\alpha$ , H $\beta$  and H $\gamma$ . These areas were removed and were not used during the analysis of the star.

## 3 RESULTS

Our results are threefold, in the first section (§3.1) we provide a brief review of the photometric data collected on HD 45677. In the next section (§3.2), we present new spectropolarimetric data taken in the *B* and *R*-bands. In our final section (§3.3), we combine these new measurements with past polarimetric observations taken within the same passband.

### 3.1 Past Photometric Data

We are mainly interested in the *V*-band photometric data from 1972 to 2005 as this is the same period over which polarimetric data has been obtained. The *V*-band variations of HD 45677 are shown in the bottom panel of Fig. 1. The star decreased in brightness from 1975 to 1980, but became brighter later on, resulting in a minimum in visual brightness in the early 1980's. De Winter & van den Ancker (1997) stated that a wide binary may cause the photometric variations, however the asymmetry of the variations and the absence of periodicity in the radial velocity measurements suggests that this may not be the case. Alternatively, they suggest that a blowout of material could have occurred in the 1950s resulting in the gradual obscuration of the star by large dust grains. The presence of a minimum and the eventual brightening is then explained by the destruction of these dust grains.

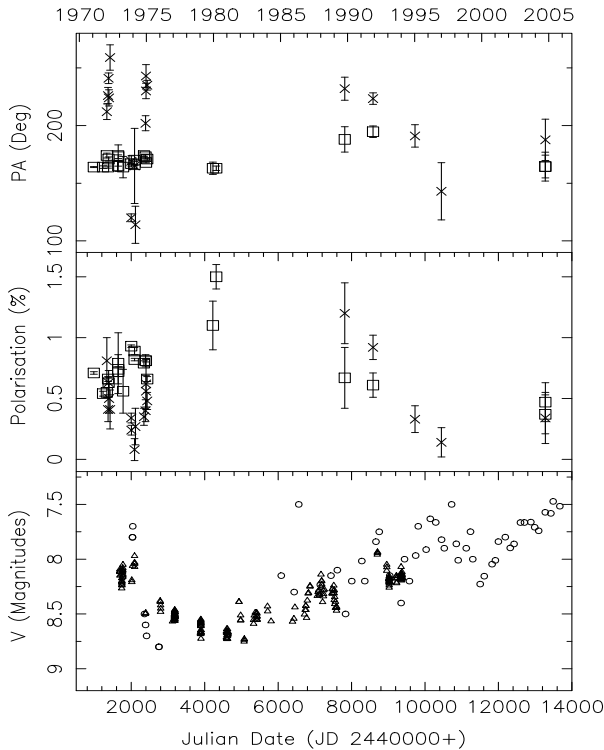
### 3.2 Spectropolarimetry

In our analysis, we shall only take account of the data around the Balmer lines, ignoring any line-effects which occur over barely resolved line components for reasons explained in Section 2.2.

Fig. 2 shows the polarisation spectrum of HD 45677 around H $\gamma$ , H $\beta$  and H $\alpha$  taken on 29/09/04. *B*-band data taken on the 28th has a lower S/N and therefore is less clear.

Source	Time Interval (JD 2440000+)
Feinstein et al. (1976)	1686-2803
Kilkenny et al. (1985)	4934-5809
Halbedel (1989)	6391-7596
De Winter & Van den Ancker (1997)	3124-9359
AAVSO	2032-13706

**Table 1.** A summary of the  $V$ -band photometry collected from the literature. In Column (2), we state the time interval over which each data set were taken.



**Figure 1.** The variability of HD 45677 in the  $B$  and  $R$ -bands over the last 30 years. The top and middle panels plot the position angle and polarimetric variability, respectively. Squares represent  $B$ -band data and crosses indicate  $R$ -band data. Both  $B$  and  $R$ -band data show significant variations in the polarisation. The lower panel shows  $V$ -band photometry for HD 45677 taken by de Winter & van den Ancker (1997), Feinstein et al. (1976), Kilkenny et al. (1985) & Halbedel (1989) [triangles] & AAVSO [circles]. The data has been grouped so that multiple observations within a short period of time are averaged. The errors associated with the photometry are less than 0.025 mag.

However, similar profiles in PA and polarisation can be seen across  $H\beta$ . The different panels in each plot display the position angle, polarisation and Stokes I parameter (top to bottom). The lower diagrams are the same data set represented in  $Q$ - $U$  space. We see line-effects across all three Balmer lines.  $H\gamma$  is a double-peaked line whose emission peaks are just above the continuum. Across the emission peaks, we see a depolarisation.  $H\beta$  is a fairly strong double-peaked emission line, but no significant changes in polarisation can be seen across the line, although a rotation in angle occurs.  $H\alpha$

is a strong, broad, double-peaked emission line. There is a change in both the polarisation and PA across the entire line, extending out to the broad wings. The presence of these line-effects indicates that the electron-scattering region around HD 45677 is aspherical.

We note, however, that the spectropolarimetric line profiles can be affected by intervening polarisation due to circumstellar and interstellar dust, as the observed polarisation is due to a vector sum of these components with the polarisation due to electrons. This can turn an otherwise straightforward depolarisation into more complex profiles (see e.g. the case of HD 87643, Oudmaijer et al. 1998). If we represent the data in  $(Q,U)$  space, however, the intervening polarisation contributes only a constant  $(Q,U)$  vector, leaving the intrinsic shape of the line-effect unaffected (Fig. 2). The  $(Q,U)$  points associated with the  $H\alpha$ ,  $H\beta$  and  $H\gamma$  emission lines are located away from the continuum and significantly, do so at the same angle.

The  $(Q,U)$  vectors from the continuum to the line-centres define the electron polarisation vector, and the angle it makes with the  $Q$  axis is a measure of the intrinsic polarisation angle. This can be directly related to the geometry of the ionised region using

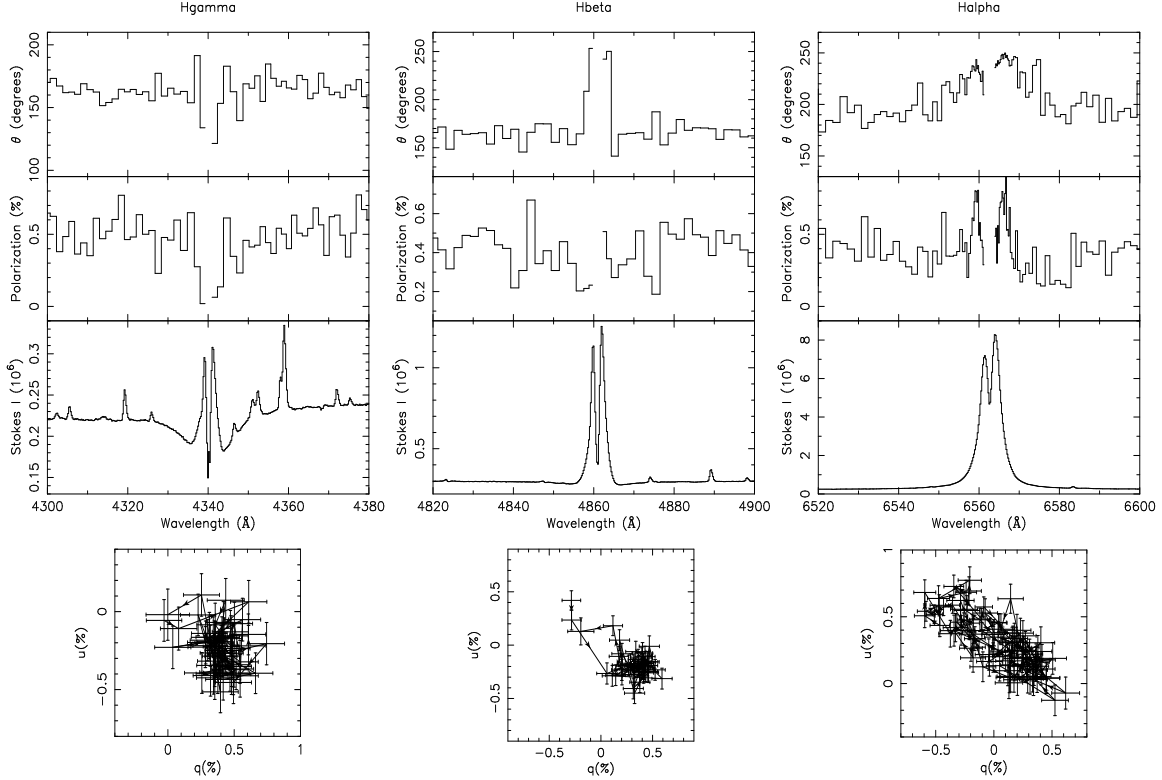
$$\theta = 0.5 \times \arctan\left(\frac{\Delta U}{\Delta Q}\right) \quad (2)$$

where  $\Delta U$  and  $\Delta Q$  are the difference between line and continuum values of  $U$  and  $Q$ , respectively.

Since the line-centres had to be removed from our data due to resolution effects, we are unable to calculate the magnitude of the electron polarisation vector. However, we are still able to measure the intrinsic polarisation angle. The direction of the electron polarisation vector associated with the line-effects across all three Balmer lines are similar and have an average intrinsic polarisation angle of  $164^\circ \pm 3^\circ$ .

We can estimate the interstellar polarisation component of HD 45677 by assuming that  $H\alpha$  is formed far from the electron-scattering region, and therefore that the polarisation at the line-centre is due to circumstellar and interstellar dust alone. Again, since the Balmer line-centres have been removed we cannot calculate the interstellar polarisation from our data. And so, we will use data from the literature.

Oudmaijer & Drew (1999) looked at the polarisation spectrum around  $H\alpha$  twice within a one year period and found intrinsic angles of  $163^\circ \pm 3^\circ$  in 1995 and  $168^\circ \pm 3^\circ$  in 1996 and a similar  $H\alpha$  line-centre polarisation at each epoch. The consistency of these results implies that the line-centre



**Figure 2.** The polarisation spectra and corresponding (Q,U) plots of HD 45677 around H $\gamma$ , H $\beta$  and H $\alpha$  (left to right) taken on 29/09/04. Plotted in the lowest triplot panel is the Stokes I spectrum, the polarisation and position angle spectra are plotted in the middle and upper panels, respectively. The data has been rebinned such that the  $1\sigma$  error in polarisation corresponds to 0.14% for H $\gamma$ , 0.1% for H $\beta$  and 0.12% for H $\alpha$ , as calculated from photon statistics. The plot below graphs the normalised Stokes parameters  $u = (\frac{Q}{I})$  and  $q = (\frac{U}{I})$  at the same bins as their corresponding triplots. The central part of the spectrum has been removed for reasons stated in the text. Line-effects can be seen across all three lines on the 29th, with a depolarisation across H $\gamma$ , no significant polarimetric effect at H $\beta$  (but a rotation in angle) and an enhancement in polarisation across H $\alpha$ . The (Q,U) points associated with the Balmer lines occur away from the continuum and at similar angles to one another, defining an average intrinsic polarisation angle of  $164^\circ \pm 3^\circ$ .

polarisation at H $\alpha$  remains the same. Therefore, we can use measurements taken by Oudmaijer & Drew to infer an interstellar polarisation and obtain an intrinsic spectrum. The authors found the H $\alpha$  line-centre polarisation to be 0.8% at an angle of  $75^\circ$ . Using these results and adopting a  $\lambda_{max}$  of 5000Å for this area of the sky (Serkowski et al. 1975), we calculated a Serkowski-law with the parameters  $p_{max} = 0.87\%$ ,  $\theta = 75^\circ$  and removed this ISP component from the data to produce the intrinsic polarisation spectrum shown in Fig. 3.

Across all of the Balmer lines, we now observe depolarisations. As the polarisation goes to zero, the relative error increases and so, any angle changes associated with the depolarisation are highly uncertain. We therefore attribute the two large rotations seen across H $\alpha$  as being due to such effects. The presence of depolarisations across the Balmer lines in the intrinsic spectrum of HD 45677 suggests that H $\alpha$ , H $\beta$  and H $\gamma$  are formed far from the electron-scattering region.

### 3.3 Broad Band Polarisation

A number of authors have conducted polarimetric studies of HD 45677, Table 2 gives a summary of the polarimetric results found in the literature in the  $B$  and  $R$ -bands. From past measurements and our new spectropolarimetric

data (Table 2), we find that HD 45677 experiences long-term polarimetric variations in both  $B$  and  $R$ -bands. The middle panel of Fig. 1 shows that the  $B$ -band polarisation peaks between 1980 and 1985, but decreases from then onwards.  $R$ -band polarimetric data suggests a similar history but without any measurements from 1976 to 1988 this cannot be confirmed. In the  $R$ -band, a rotation of  $90^\circ$  occurs within a two year period, while angle changes in the  $B$ -band do not exceed  $30^\circ$  over 32 years.

Comparing the polarimetric and photometric observations, we find that as the observed  $B$ -band polarisation increases (from 1975 to 1980) the star becomes fainter and as the polarisation decreases (from 1982 to 1995) the star becomes brighter. Furthermore, the minimum in visual brightness corresponds to a peak in polarisation. These changes are similar to those of UXOR variables, where surrounding dust clouds cause simultaneous changes in polarisation and photometry. However, de Winter & van den Ancker investigated the  $B-V$  photometry of HD 45677 and show that the colour of the object continues to become redder even when the star is at minimum visual brightness. This is inconsistent with UXOR variations.

Let us now discuss the observation that the polarisation angles are more variable in the  $R$ -band than the  $B$ -band. In general, the  $R$ -band data has a lower continuum polarisation

Paper	Date Observed	B/R band	%P	P.A. (Deg)
Coyne & Vrba (1976)	29/01/71	B	$0.71 \pm 0.01$	$164 \pm 0.4$
	08/10/71	B	$0.54 \pm 0.02$	$164 \pm 1.1$
	19/01/72	B	$0.55 \pm 0.04$	$174 \pm 2.1$
	21/02/72	B	$0.66 \pm 0.02$	$164 \pm 0.9$
	07/03/72	B	$0.63 \pm 0.04$	$171 \pm 1.8$
	22/11/72	B	$0.74 \pm 0.12$	$165 \pm 4.7$
	23/11/72	B	$0.79 \pm 0.25$	$174 \pm 9.2$
	24/11/72	B	$0.72 \pm 0.04$	$173 \pm 1.6$
	04/04/73	B	$0.56 \pm 0.18$	$164 \pm 9.3$
	12/11/73	B	$0.93 \pm 0.01$	$167 \pm 0.3$
	11/02/74	B	$0.89 \pm 0.03$	$170 \pm 1.0$
	12/02/74	B	$0.82 \pm 0.01$	$166 \pm 0.4$
	24/10/74	B	$0.79 \pm 0.02$	$174 \pm 0.7$
	08/12/74	B	$0.81 \pm 0.05$	$173 \pm 1.8$
	18/12/74	B	$0.81 \pm 0.01$	$168 \pm 0.4$
Barbier & Swings (1982)	21/01/75	B	$0.66 \pm 0.02$	$171 \pm 0.9$
	12/79	B	$1.10 \pm 0.20$	$173.0 \pm 5.3$
Gnedin et al. (1992)	03/80	B	$1.50 \pm 0.10$	$173.0 \pm 1.9$
	10/89	B	$0.67 \pm 0.25$	$8.0 \pm 11.0$
Schulte-Ladbeck et al.(1992)	12/90	B	$0.61 \pm 0.10$	$14.7 \pm 5.0$
This paper	28/09/04	B	$0.37 \pm 0.16$	$164.0 \pm 12.1$
	29/09/04	B	$0.47 \pm 0.16$	$165.0 \pm 9.5$
Coyne & Vrba (1976)	17/01/72	R	$0.81 \pm 0.19$	$212 \pm 6.8$
	21/02/72	R	$0.41 \pm 0.10$	$226 \pm 7.1$
	08/03/72	R	$0.63 \pm 0.10$	$241 \pm 4.6$
	18/03/72	R	$0.50 \pm 0.12$	$224 \pm 7.0$
	16/04/72	R	$0.41 \pm 0.16$	$259 \pm 11$
	12/11/73	R	$0.34 \pm 0.04$	$120 \pm 3.4$
	17/11/73	R	$0.24 \pm 0.04$	$169 \pm 4.8$
	11/02/74	R	$0.08 \pm 0.09$	$165 \pm 32.6$
	06/03/74	R	$0.27 \pm 0.15$	$114 \pm 16.1$
	25/10/74	R	$0.35 \pm 0.07$	
	08/12/74	R	$0.40 \pm 0.09$	$202 \pm 6.5$
	19/12/74	R	$0.56 \pm 0.13$	$230 \pm 6.7$
	20/12/74	R	$0.62 \pm 0.21$	$243 \pm 9.8$
	21/01/75	R	$0.48 \pm 0.07$	$235 \pm 4.2$
Gnedin et al. (1992)	10/89	R	$1.20 \pm 0.25$	$52.0 \pm 10.0$
Schulte-Ladbeck et al.(1992)	12/90	R	$0.92 \pm 0.10$	$43.4 \pm 5.0$
Oudmaijer & Drew (1999)	10/01/95	R	$0.33 \pm 0.11$	$11.0 \pm 9.7$
	29/12/96	R	$0.14 \pm 0.12$	$143.0 \pm 24.8$
This paper	29/09/04	R	$0.34 \pm 0.22$	$8.0 \pm 18.1$

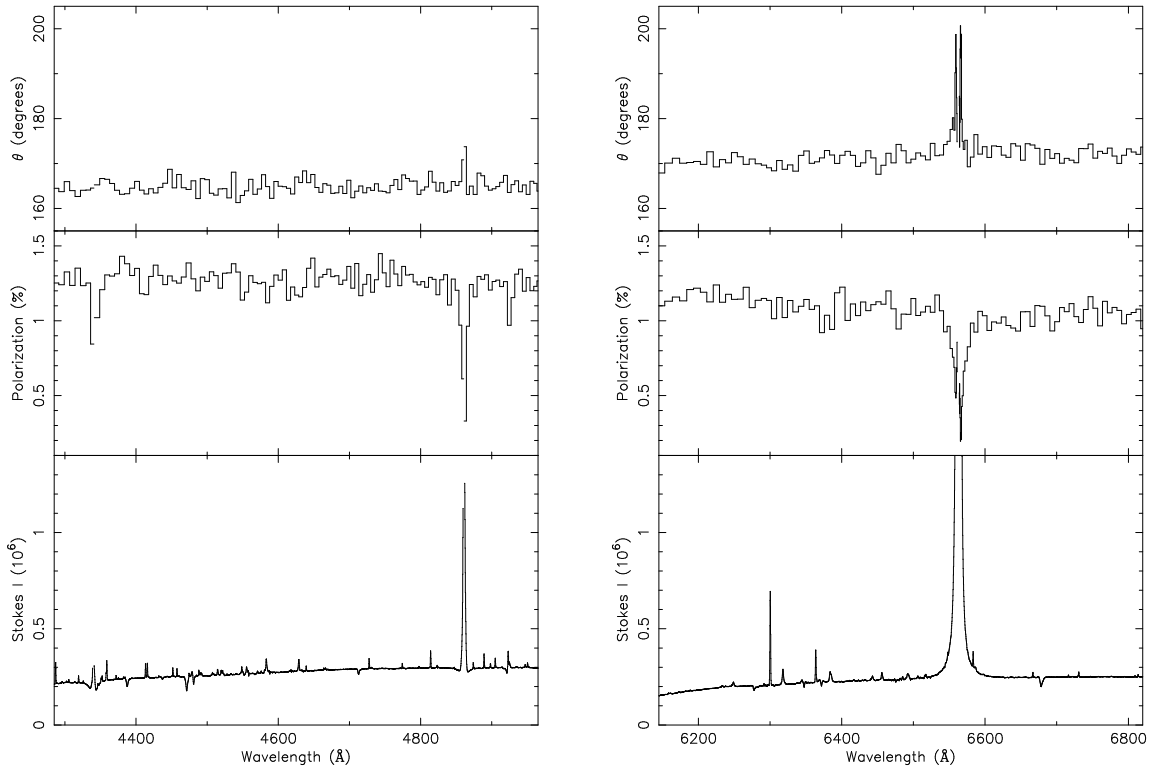
**Table 2.** Past and present polarisation observations of HD 45677. Column (1) gives the authors who have obtained the measurements. Where no errors in angle were given, errors were calculated using the method described in Section 2.1. Measurements from new spectropolarimetric data (i.e. this paper) were obtained by measuring average polarisations and position angles between 4400-4800Å in the *B*-band and between 6200-6500Å and 6600-6800Å in the *R*-band.

than in the *B*-band. Since the polarisation of HD 45677 is already low, similar absolute errors are more significant in the *R*-band than those in the *B*-band. This affects the position angle measurements more than the corresponding polarisation measurements, as the uncertainty in the determination of the PA, which results from a ratio, will be substantial in the case of large errors bars in *Q* and *U*. And so, the errors in PA in the *R*-band are often greater than those which can be calculated using Eqn 1.

When we ignore all position angles for observations with a polarisation smaller than  $3\sigma$ , we find that most of the *R*-band data is removed. This means that the quality of the *R*-band data is inadequate to investigate whether the PA rotates more in the *R*-band than in the *B*-band.

In Fig. 4 we investigate the distribution of the polarimetric data in *Q-U* space. We do not use the *R*-band data

as significant errors in *Q* and *U* will result in a large uncertainty in the (*Q,U*) vectors between points, producing a large uncertainty in the observed distribution. We find that the *B*-band data is well fitted using a least-squares fit. This implies that the relationship between *Q* and *U* is linear and the geometry associated with the production of the *B*-band polarisation remains at the same angle over time. The gradient of the fit is related to the geometry of the circumstellar material by Eqn. 2. We find an intrinsic PA of  $175^\circ \pm 1^\circ$ . This is remarkably close to the value derived for the electron-scattering region.

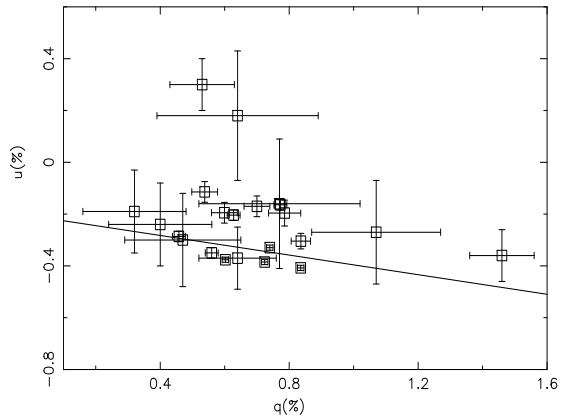


**Figure 3.** The intrinsic polarisation spectrum of HD 45677 taken on 29/09/04 over the *B* and *R*-bands. The data are rebinned such that the  $1\sigma$  error in the polarisation corresponds to 0.06% as calculated from photon statistics. The intrinsic spectrum was produced by removing an estimation of the ISP, using the line-centre polarisation at  $H\alpha$  measured by Oudmaijer & Drew (1999), from the polarisation data collected in 2004. The Balmer lines all show depolarisations indicating that the enhancement initially observed was due to foreground polarisation.

#### 4 DISCUSSION

We have presented medium-resolution spectropolarimetric observations of HD 45677. The presence of line-effects within the data set suggests that the geometry of the ionised region around the object is aspherical. Using  $H\alpha$  line-centre polarisation measurements taken by Oudmaijer & Drew (1999) we calculated a Serkowski-law with the parameters  $p_{max} = 0.87\%$ ,  $\theta = 75^\circ$  at a  $\lambda_{max} = 5000\text{\AA}$  in order to arrive at the intrinsic polarisation due to electron scattering alone.

In passing, we note that this value can not necessarily be compared to the determination of the ISP by Coyne & Vrba (1976), who derived a Serkowski-law with the parameters  $p_{max} = 0.65\%$ ,  $\theta = 170^\circ$  at a  $\lambda_{max} = 5000\text{\AA}$  using consistent polarimetric measurements at short wavelengths ( $3650\text{\AA}$ ). This value was subsequently used by Schulte-Ladbeck et al. (1992) who found that the polarisation increased by  $> 1\%$  from the *B*-band to the *R*-band and a  $90^\circ$  flip in PA occurred from the *UV* to the red. They also observe an enhancement in polarisation over  $H\alpha$  leading them to conclude that the Balmer line is formed close to the star. It is important to note that Coyne & Vrba calculated the ISP alone, while our value also takes into account the polarisation due to circumstellar dust and therefore will be different. Thus, the enhancements seen across  $H\alpha$  and the changes in polarisation observed by Schulte-Ladbeck et al. may still be affected by foreground polarisation effects due to circumstellar dust. In our intrinsic spectrum, we find that depolarisations occur across all of the Balmer lines, suggesting that the enhance-



**Figure 4.** (Q,U) data of HD 45677 measured in the *B*-band over the last 30 years. The data can be well fitted by a least-squares fit, suggesting a linear relationship between Q and U and constant PA. As the intrinsic polarisation angle does not change, the geometry of the circumstellar material remains constant over time.

ments observed were due to foreground polarisation effects and that the Balmer lines are formed far from the electron-scattering region.

Both polarimetric and photometric variability can be seen in HD 45677. These changes seem to be linked, with increasing polarisation occurring during periods of decreasing

visual brightness and vice versa. We find that the  $B$ -band polarimetric data can be well fitted using a least-squares fit, suggesting that the geometry of the circumstellar material remains constant over time. The gradient of the fit is related to the intrinsic PA by Eqn. 1, giving an angle of  $175^\circ \pm 1^\circ$ , which is along the same plane as the electron-scattering region as measured using the observed line-effects.

The combination of photometric and polarimetric changes and the linear distribution of the (Q,U) points suggests that the variations in polarisation are due to changes in the dust polarisation component. De Winter & van den Ancker (1997) explained that the photometric variations may be caused by a wide binary or a blowout of material occurring in the 1950s. Spectro-astrometric measurements of the star at  $H\alpha$  by Baines et al. (2006) suggest the presence of a wide companion at a PA of  $150^\circ$ . However, a wide binary is unlikely to produce significant variations in polarisation (1%) over a period of 30 years (as the object would not intercept enough starlight for the polarisation changes to be significant).

Alternatively, a blowout by the star may explain variations in the  $V$ -band photometry and polarisation by, for example, the creation and destruction of large grains. The very fact that we observe any changes in polarisation implies the blowout was aspherical. Fig. 4 shows that these changes occur along a constant angle, therefore, this suggests that the blowout has a flattened geometry at an intrinsic PA of  $175^\circ \pm 1^\circ$ . The intrinsic polarisation angle associated with the line effects across the Balmer lines showed that the aspherical ionised region occurs at a PA of  $164^\circ \pm 3^\circ$ .

Monnier et al. (2006) interferometrically imaged HD 45677 in the near- $IR$  and proposed that the star is surrounded by an elongated, skewed dust ring. They suggest that this geometry would produce a net linear polarisation with a PA of  $70^\circ$ . We propose that the aspherical blowout occurs along the same plane as the ionised region and, if the circumstellar environment is optically thin and multiple scatterings are not important (see Vink et al. 2005), the proposed angle of the blowout and the ionised region could be rotated by  $90^\circ$  to define an angle on the sky of  $85^\circ \pm 1^\circ$  and  $74^\circ \pm 3^\circ$  respectively, which lies along the same plane as the elongated dust ring proposed by Monnier et al. (2006).

## 5 CONCLUSION

We have presented new spectropolarimetric data combined with past photometric and broad-band polarimetric observations on HD 45677. From our spectropolarimetric data we have confirmed that the ionised region is aspherical and that the Balmer lines in the  $B$  and  $R$ -bands are formed far from the electron-scattering region. We found the object experiences variations in both  $V$ -band photometry and  $B$  and  $R$ -band polarimetry and that these changes are linked. We suggest that the results may be explained by a blowout of material by the star occurring in the 1950s. In observing these polarisation changes and from the (Q,U) data we conclude that this blowout occurred aspherically along the same plane as the ionised region.

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## REFERENCES

- Baines D., Oudmaijer R. D., Porter J. M., Pozzo M., 2006, *MNRAS*, 367, 737
- Barbier R., Swings J. P., 1982, in Jaschek M., Groth H.-G., eds, *IAU Symp. 98: Be Stars Polarization in peculiar emission-line objects*. pp 103–106
- Coyne G. V., Vrba F. J., 1976, *ApJ*, 207, 790
- de Winter D., van den Ancker M. E., 1997, *A&AS*, 121, 275
- Feinstein A., Garnier R., Vogt N., Swings J. P., Heck A., Manfroid J., 1976, *A&A*, 51, 269
- Gnedin Y. N., Kiselev N. N., Pogodin M. A., Rozenbush A. E., Rozenbush V. K., 1992, *Soviet Astronomy Letters*, 18, 182
- Grady C. A., Bjorkman K. S., Shepherd D., Schulte-Ladbeck R. E., Perez M. R., de Winter D., The P. S., 1993, *ApJ*, 415, L39
- Halbedel E. M., 1989, *PASP*, 101, 999
- Henden A. A., 2006, Observations from the AAVSO International Database, private communication
- Israelian G., Friedjung M., Graham J., Muratorio G., Rossi C., de Winter D., 1996, *A&A*, 311, 643
- Kilkenny D., Whittet D. C. B., Davies J. K., Evans A., Bode M. F., Robson E. I., Banfield R. M., 1985, *South African Astronomical Observatory Circular*, 9, 55
- Lamers H. J. G. L. M., Zickgraf F.-J., de Winter D., Houzi-aux L., Zorec J., 1998, *A&A*, 340, 117
- Monnier J. D., Berger J. ., Millan-Gabet R., et al. 2006, *ApJ* in press. (astro-ph/0606052)
- Muratorio G., Rossi C., Friedjung M., 2006, *A&A*, 450, 593
- Oudmaijer R. D., Drew J. E., 1999, *MNRAS*, 305, 166
- Oudmaijer R. D., Proga D., Drew J. E., de Winter D., 1998, *MNRAS*, 300, 170
- Schulte-Ladbeck R. E., Shepherd D. S., Nordsieck K. H., et al. 1992, *ApJ*, 401, L105
- Serkowski K., Mathewson D. L., Ford V. L., 1975, *ApJ*, 196, 261
- Sorrell W. H., 1989, *MNRAS*, 241, 89
- Swings J. P., 1973, *A&A*, 26, 443
- Vink J. S., Drew J. E., Harries T. J., Oudmaijer R. D., Unruh Y., 2005, *MNRAS*, 359, 1049

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